

SOLID SULFUR IN VACUUM: SUBLIMATION EFFECTS ON SURFACE MICRO-TEXTURE, COLOR, AND SPECTRAL REFLECTANCE, AND APPLICATIONS TO PLANETARY SURFACES; D. B. Nash, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

A new form of sulfur that is white at room temperature, and very fluffy in texture, has been found in laboratory experiments on the effects of vacuum sublimation (evaporation) on solid sulfur. This work is an outgrowth of proton sputtering experiments on sulfur directed toward understanding Jovian magnetospheric effects on the surface of Io (Nash, 1985).

Fluffy white sulfur is formed on the surface of solid yellow, tan, or brown sulfur melt freezes in vacuum by differential (fractional) evaporation of two or more sulfur molecular species present in the original sulfur: S_8 ring sulfur is thought to be the dominant sublimation (evaporation) phase lost to the vacuum sink, and polymeric chain sulfur (S_u) the dominant residual phase that remains in place forming the residual fluffy surface layer.

The microscopic structure of the fluffy sulfur layer determined from scanning electron microscope (SEM) images is skeletal with a lacy-like fabric and with filamentary components having a scale size of $<1 \mu\text{m}$. It appears from its relatively organized structure to be dominated by molecular forces rather than adhesive forces between particulate grains such as that described for water/clay sublimate residues by Saunders et al. (1985). In the SEM pictures it resembles cellular sulfur material described by Tuinstra (1967) resulting from dissolving melt-freeze sulfur in liquid CS_2 solvent and obtaining an insoluble polymeric residue. The residual subliming surface becomes very porous (up to about 98% void space) and has a bulk thickness of $\sim 0.5 \text{ mm}$ after ~ 800 hours at 2×10^{-7} torr ($\sim 3 \times 10^{-10}$ atm.)

The color of the evaporating surface changes from the original -- which at room temperature ($\sim 300 \text{ K}$) may be yellow, tan, or brown depending on the pre-freeze melt temperature (393-713 K) -- to white with a faint greenish-yellow tint. For fresh sulfur melt-freeze samples evaporating at $\sim 300 \text{ K}$ in $\sim 10^{-7}$ torr vacuum there occur significant spectral, color, and albedo effects in as little as 10 hours, becoming uniformly white within 300 hours, and progressive changes in spectral details continue for at least 1200 hours. Once removed from vacuum conditions the material is stable in form and color with time (for at least several months).

The reflectance spectrum of the original sulfur surface in the UV/VIS (0.35 to 0.70 μm) range is greatly modified by formation of the fluffy surface layer: the blue absorption band-edge and shoulder move 0.05 to 0.06 μm toward shorter wavelengths resulting in a permanent increase in reflectivity near 0.42 - 0.46 μm by as much as 400% or more, and the UV reflectivity below 0.40 μm is reduced to about 1/3 its original level to as low as 2%. The new band-edge and shoulder positions are temperature sensitive, as in unmodified sulfur, shifting to shorter wavelengths with decreasing temperature, and returning to their pre-cooled wavelength with temperature recovery; but with fluffy white sulfur the temperature-induced excursion range of the absorption edge is almost entirely within the violet and UV whereas in ordinary sulfur it is mostly in the green and blue wavelengths.

The sublimation (evaporation) rate of sulfur from fresh frozen sulfur melt at initial exposure to high vacuum ($\sim 10^{-7}$ torr) is on the order of 2×10^{15} S cm⁻² sec⁻¹ at ~ 300 K (in agreement with previous measurements by Bradley, 1951), increasing steeply with temperature, decreasing with higher vacuum pressure, and decreasing with vacuum exposure time reaching an equilibrium flux of about $1-4 \times 10^{14}$ S cm⁻² sec⁻¹ after ~ 1200 hours.

This remarkable form of lacy, fluffy, white sulfur should exist in large quantity on the surface of Jupiter's satellite Io, especially in hotspot regions if there is solid free sulfur there that has solidified from a melt. Its color and spectra will indicate relative crystallization age on a scale of days to months and/or surface temperature distribution history. It suggests that for a sulfur flow surface there could be a class of surface hotspots that have a white-is-hot relationship, an inverse variant of, but not in conflict with, the albedo-vs-temperature relation demonstrated in the Io data by McEwen et al. (1985). The concepts to be developed from this work on fluffy sulfur are expected to be helpful in understanding properties of Io's surface such as composition, adsorbtivity, thermal inertia, polarization, photometry (with solar phase angle), and post-eclipse brightening. The flux of subliming sulfur from hotspots on Io could be a copious and continuous source supplying the Io sulfur torus.

Material with structure similar to that of fluffy sulfur could exist on surfaces of other small (airless) planetary bodies, including comets, that have multiple surface constituents of differing volatility.

References:

- Bradley, R. S. (1951). The rate of evaporation and vapour pressure of rhombic sulfur. Proc. Roy. Soc., A205, 553-563.
- McEwen, A. S., D. L. Matson, T. V. Johnson, L. A. Soderblom (1985). Volcanic hotspots on Io: Correlation with low-albedo calderas. Submitted to J. Geophys. Res.
- Nash, D. B. (1985). Proton irradiation of sulfur: Sputtering yields, spectral reflectance changes, and applications to Io. Bull. Am. Astron. Soc., 17, 921.
- Saunders, R. S., F. A. Fanale, T. J. Parker, J. B. Stephens (1985). Properties of filamentary sublimation residues from dispersions of clay in ice. Submitted to Icarus.
- Tuinstra, F. (1967). Structural aspects of allotropy of sulfur and the other divalent elements. Uitgeverij Waltman, Delft (The Netherlands). 110 p.